Original Research Paper

A Study on Ecophysiology of Tea *(Camellia sinensis)* with special reference to the Influence of Climatic Factors on Physiology of a Few Selected Tea Clones of Darjeeling

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ABSTRACT

Influence of climatic factors viz. ambient temperature, photosynthetically active radiation, wind velocity, sunshine hour on various physiological parameters of three Darjeeling tea clones was studied. Net photosynthesis, stomatal conductance, transpiration and leaf water potential of the tea plants were badly affected during drought. Rate of photosynthesis was lowest in April. In dry period, humidity was found to be the most important limiting factor. Low temperature and high rainfall affected net photosynthesis, though to a lesser extent as compared to drought. Post monsoon period was found to be most conducive for physiological activity. High light intensity was not a limiting factor as long as moisture was adequate. Seasonal variation of physiological parameters was pronounced but there was no significant variation among three clones.

Keywords : Tea physiology; climatic factors; Darjeeling tea clones

Introduction

Characteristics of the plant or genotype, affect the way in which a crop will react to the environment. Many agricultural experiments are carried out that yield results of limited value because no consideration is given to important aspects of the environment, or no attempt is made to understand the interacting effect of cultural method on yield (Williams and Joseph, 1976). The main climatic variables influencing rates of shoot extension and yield of tea are temperature, rainfall, evaporation and the saturation deficit of the air and through their influence on plant and soil water deficit of the air and through their influence on plant and soil water deficits (Carr, 1972; Squire and Callandar , 1981 ; Stephens and Carr, 1990). Eden (1976) felt that it was difficult to specify the ideal or the average climate that tea requires. Photosynthetic efficiency is the primary component of dry matter productivity. According to Stephens *et al* (1992), ecophysiology of tea has several applications : it can be used to assist planners in assessing the yield potential of new (or existing) areas of tea and to estimate likely benefits from irrigation (Stephens and Carr, 1988). It can also be used to assess the benefits of shade in different location (Hadfield, 1974) and in the development of selection criteria for new clones, based on a knowledge of the base temperature for shoot growth (Stephens and Carr, 1990). Further, it can be used to help to specify objective harvesting policies.

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Effect of weather on crop

Crop growth and production depend on the interaction of biological system which is the plant or more often a population of plants and the physical environment in which the plant grows. The total growth and production are in fact derived from the environment through the special mechanism and properties possessed by the biological system (Williams and Joseph, 1976).

Huang Shoubo (1989) studied the meteorology of tea plant in China. He observed that temperature influenced the growth, development and yield of tea plant. In China, optimum temperature for most varieties was in the range 20 – 30°C. According to him, tea plants required 1000 – 1400 mm of annual rainfall : 100 – 150 mm of rain per month except for the high temperature months. Relative humidity of 80 –

90% was favourable for tea plants, below which shoot growth was affected.

Tanton (1982) reported that shoot extension stopped below about 12.5°C air temperature. Soil temperatures between 18 and 25°C did not affect shoot extension. Othieno (1982) reported that lower soil temperature affected growth and yield.

Hadfield (1976) found maximum CO_2 uptake at 30 – 35°C. There was rapid fall beyond 37°C and there was no net photosynthesis at 42°C. Under natural conditions, temperature of fully exposed leaves was 2°C to 12°C higher than ambient temperature. Nakayama and Harada (1962) from Japan found that growth was most rapid at 30°C and ceased below 12.5°C. Carr and Stephens (1992) reported that the minimum air temperature required to support shoot growth appeared to be 13 – 14°C with an optimum range of 18 – 30°C. Day time maximum temperature in excess of 30 C and night temperature below about 14°C probably lead to a reduction in the growth rate. The minimum leaf temperature necessary to initiate shoot extention was apparently 12°C and at leaf temperature of about 35°C the rate of net photosynthesis falls off quickly. Long sunshine hours are probably essential for maximum yield. In most areas, 150 mm of rain each month i.e. 1800 mm of annual rainfall will ensure continuous crop production.

Manivel (1980) reported that the maintenance leaves below the plucking surface fixed CO_2 photosynthetically and supply the photosynthates to other parts of the plant. All the mature leaves in the plants were photosynthetically active even under the cold weather conditions prevailing in December. He found that even the fifth leaf from the top was contributing photosynthates towards the growth of pluckable shoots at the top. He observed highest rate of photosynthesis in the topmost leaf of the maintenance foliage.

Manivel and Hussain (1982) reported that topmost leaf in a canopy (maintenance canopy) contributed the highest proportion of photosynthates to the pluckable shoots. Manivel (1978) also referred that pluckable 'two and a bud' also photosynthesizes, but to a much lesser extent than the mature leaves. Maintenance foliage in tea is the main source of carbohydrate.

Rustagi and Barman (1993) had stated that inter-flush dormancy was caused by low availability of moisture and various other factors whereas winter dormancy was caused by the interaction of some environmental factors like short day length and low temperature.

Effect of Temperature

Carr (1985) suggested that even small variations (approximately 1°C) in air temperature could have pronounced effect on shoot extension rates. In general, mean minimum temperatures below 13°C was likely to bring about damage to the foliage and retardation of growth : Mean maximum temperature above 30°C was likely to be accompanied by humidity so low that a similar cessation of active development was inevitable (Eden, 1976). Tea exhibits a wide range of temperature tolerance and is cultivated from the humid equatorial regions to subtropical and temperature latitudes. Tea is also grown in high altitudes in the tropics and subtropics. Huang Shoubo (1989) reported that in China, optimum temperature of most tea varieties is in the range of 20 – 30°C. Barbora (1994) inferred that photosynthetic response to temperature was mainly due to change in mesophyll activity rather than stomatal conductance. Steward (1960) referred that temperature limits for photosynthesis in the intact cell are given on the one hand by the damage of essential structure due to disruptive crystal formation and on the other hand by heat denaturation of enzymes and structural proteins. But, according to Rosenberg (1974), the photosynthetic reaction was not strongly affected by the ambient temperature, as long as lethally high or low temperatures were not encountered.

Effect of Light

The maximum light energy that a tea leaf can use for photosynthesis varies from clone to clone even under optimal conditions (Barua, 1993).

Light affects crop growth and production both through its use in photosynthesis and through photoperiodic reactions. Two aspects of photosynthetic light are of interest in studying crop production; the total amount of incoming light which is suitable for photosynthesis and the amount of light which is available for or can be utilized by the crop (Williams and Joseph, 1976). Murty (1988) pointed out that reduction in photosynthesis under low light could be attributed to high stomatal resistance to CO_2 exchange.

Rajkumar *et al* (1999) observed that sub (less than 900 umol m^{-2} s^{-1}) and supra optimal (greater than 1200 umol m^{-2} s^{-1}) levels of PAR inhibited photosynthesis significantly.

Effect of Water Stress

Barbora (1994) inferred that water stress reduces photosynthesis due to stomatal closure. Humidity is of importance in tea physiology primarily because of its influence in determining the loss of moisture by evapotranspiration (Banerjee, 1993). The success of tea in high altitude sites partly appears to be related to the crops requirement for high moisture levels (Williams and Joseph, 1976).

Murthy (1995) reported that tea bushes were benefited by high atmospheric humidity. He added that low humidity affected the physiological activities adversely by influencing the cell sap concentration. Many authors have reported that irrigation plays an important role in combating moisture stress (Ali – Zade, 1950; Petinov, 1961). Stocker *et al* (1954) suggested that strategic *sprinkler water used than furrow or ground* irrigation. Fordham (1969) reported that internal water stress was reduced by ground irrigation but it did not have any lasting effect on temperature and vapour pressure of the atomosphere except for the short periods when water was actually being applied overhead. Lebedev (1962) reported that intermittent sprinkling of water reduced temperature and increased humidity around tea bushes in Russia. An experiment conducted in Malawi showed that misting the tea in hot dry months removed adverse effects of dry air and allowed shoots to grow at the same rate as shoot growing at the same mean effective daily temperature in the rainy season (Tanton, 1982).

Barua (1989) reported that low temperature and day length apparently interact including dormancy but their respective roles were not yet clear. Several scientists have attempted to select plant with high stomatal *resistance increased under* water stress condition but the conductance reduced Soil moisture deficit reduced the transpiration rate (Barbora, 1994). In China type of clones the transpiration was lower at the higher soil moisture level, but its depression was minimum at low soil moisture status (Barbora, 1994). Soil moisture stress decreases transpiration rate (Handique and Manivel, 1990).

Effect of wind

Banerjee (1993) reported that wind turbulence could reduce high temperature which otherwise would adversely affect photosynthesis. However, direct effect of wind speed on physiology of growth and productivity of tea is not known. Williams and Joseph (1976) reported that wind increases transpiration so that water deficits are liable to occur sooner and stomatal closure may then reduce photosynthesis. Secondly, renewal of air at the leaf surface will maintain the CO_2 concentration around the leaf at normal levels under conditions of rapid CO_2 uptake. With limiting moisture, wind may be expected to reduce photosynthesis, on the other hand, with a favourable moisture balance for the plant, wind is likely to increase photosynthesis.

Role of Water Potential

Handique and Manivel (1986) inferred that drought tolerant clones consistently exhibited higher water potential. Manivel and Handique (1983) inferred that age of plants had no significant effect on water potential. During very cold winter months, value of water potential decreased compared to wet summer months (Manivel and Handique, 1983. Rustagi and Barman (1993 a) have reported that clones of China origin exhibited higher water potential compared to Assam clones.

Role of Leaf Temperature

Leaf temperature directly affects plant metabolic activities. Singh and Sahay (1992) observed that leaf temperature above 35°C was too critical for photosynthesis. According to Carr and Stephens (1992) minimum leaf temperature necessary to initiate shoot extension is apparently 12°C and at leaf temperature above 35°C, the rate of photosynthesis falls off quickly, Mcwilliam (1988) referred that the genotypes with higher leaf temperature under water stress conditions were most resistant to drought than genotypes with lower leaf temperature.

Materials and Methods

The work was carried out at Darjeeling Tea Research Centre at Kurseong (1240m a.m.s.l.; 26°55'N, 88°12' E) on three Darjeeling clones. The tea in the experimental area was planted in 1985 in double hedge at a spacing of 90 cm. X 60 cm. X 60 cm.. There were five replications , each plant was a replication.The parameters studied were net photosynthesis, stomatal conductance, transpiration, leaf water potential and leaf temperature. Data were recorded during early morning at bimonthly interval, when rate of net photosynthesis was highest. The first , second and third leaves of the maintenance canopy were taken for study. The instruments used were a portable photosynthesis system (LI 6200), a dew – point microvoltmeter (HR 33 T) and a portable area meter (LI 3000 A) .

The salient characteristics of the three clones are given below:

Bannockburn 157 : It is a medium sized, dark green glossy leafed China hybrid clone with dense plucking points and many trailing lower branches . It is drought resistant. It is a very early flusher and keeps flushing till late December. With adequate irrigation in dry weather, it starts flushing in mid – January.

Phoobshering 312: It is a China hybrid clone with medium size, semi – erect, dark green leaf with pronounced serration , matty foliage and wavy margin,widespread and compact frame. It thrives well on all aspects but prefers north slope and high altitude.

Tukdah 78 :It is a very vigorous China hybrid clone with erect dark green leaf. It is drought resistant. It is a fairly good spreader with lax frame.

The mean weather parameters are given in table1.

Table 1.
Monthwise weather report collected from the Agro-met observatory adjacent to the trial plots

Weather parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max. Temperature (°C) (Mean)	14.6	14.8	19.3	22,8	22.7	23.5	23.5	23.3	22.6	20.7	19.4	16.6
Min. Temperature (C) (Mean)	5.9	8.4	11.5	15.1	16.2	18.3	18.4	18.9	17.4	14.9	12.4	10.2
Soil temperature (10 cm. depth,°C) (Mean)	10.4	12.4	16.6	20.9	21.3	22.5	22.4	22.4	21.3	19.0	15.5	12.3
Sunshine duration (h. day^{-1}) (Mean)	3.5	3.9	5.1	5.7	3.5	1.7	0.9	1.5	1.2	4.1	5.7	5.1
Relative humidity (%)(Mean)	78.8	74.4	71.2	67.9	84.2	82.0	94.7	94.0	92.8	85.6	75.7	76.8
Total rainfall (mm)	30.0	15.0	27.6	42.6	228.4	738.2	990.3	745.6	549.2	101.6	0.0	10.7
Wind velocity (Km. hour^{-1})(Mean)	2.6	4.0	4.0	5.3	5.3	5.4	5.3	4.4	2.9	4.2	5.0	4.3

1) Mean values of three years
2) Photosynthetically active radiation recorded during recording of net photosynthesis and other physiological data.

Mean weather data collected (inside the leaf chamber of Portable photosynthesis system) during recording net-photosynthesis and other physiological parameters is presented in table 2 .

Table 2.
Weather condition inside the leaf chamber during recording of physiological data

Month	Ambient Temperature (C)	Relative Humidity (%)	PAR (u mol m^{-2} s^{-1})	Ambient CO_2 (ppm)
Feb	17.03	42.06	706.7	335.9
Apr	28.31	25.54	1361.0	362.9
Jun	28.08	49.21	1287.0	343.1
Aug	28.22	59.50	561.8	326.3
Oct	27.18	53.96	1384	328.2
Dec	21.98	47.60	1193.0	319.9

RESULTS AND DISCUSSION

Net Photosynthesis (Pn) under Varied Weather Conditions

In February (winter) air temperature was lowest, so were soil moisture, relative humidity and rainfall. Sunshine hour, photosynthetic photon flux density and wind velocity were moderate. Rate of net photosynthesis was low but higher than that of April. During summer (April) the rate of net photosynthesis was lowest when the air and soil temperature, light intensity and wind velocity were high; sunshine hour was highest but relative humidity was lowest. During monsoon, rainfall, soil and atmospheric moisture, air and soil temperatures were high but sunshine duration was low. Under these net photosynthesis was in the intermediate range.

In February, although soil moisture was very low, relative humidity was higher than that of April . Rate of net photosynthesis was higher in February compared to April. In April (Summer) at higher air temperature (approx. 26°C), the rate during June and August (monsoon), although the temperature was considerably higher than that of April, the rate of net photosynthesis was considerably higher than that of April). During April, the light intensity was very high but during monsoon, the intensity was low. This result confirmed the finding of Roberts and Whitehouse (1976) that at low light intensities, the photosynthetic rate is independent of temperature but at higher light intensities photosynthesis affected by temperature. On the other hand, reduction in the rate of net photosynthesis in February was the result of low temperature encountered by the plants – when the soil moisture content was lowest and atmospheric humidity and light intensity were also low. In the month of April – air temperature, photosynthetic photon flux density, sunshine hour, wind velocity and soil temperature were very high but lowest was the rate of net photosynthesis, transpiration, stomatal conductance and leaf water potential. This is mainly because of lowest relative humidity and very low soil moisture. But present study has revealed that more than soil moisture, atmospheric humidity was important for physiological activity of the tea plants. Because soil moisture was very low in February too but the rate of net photosynthesis, stomatal conductance, transpiration etc. were higher than that of April. On the other hand, very high humidity also was found to affect the rate of net photosynthesis during monsoon. During post – monsoon, when relative humidity was moderate, very high rate of net photosynthesis, stomatal conductance and transpiration was observed.

Table 2:
Seasonal changes in net photosynthesis (Pn) (u mol m^{-2} s^{-1}) of three genotypes of tea.

Month	Clones			Mean	LSD
	B157	P 312	T 78		P=0.05
February	7.502	6.122	6.291	6.6	0.95
April	2.817	3.672	3.081	3.2	0.68
June	8.443	8.398	7.210	8.0	0.59
August	9.185	9.801	8.552	9.2	1.59
October	11.58	10.024	11.072	10.9	1.32
December	10.557	10.144	9.247	10.0	0.53

Stomatal Conductance

High rate of stomatal conductance was observed in October, December and February and lowest in April (Table 3)

Table 3:
Seasonal changes in stomatal conductance (gs) (cm s^{-1}) of three genotypes of tea.

Month	Clones			Mean	LSD
	B157	P 312	T 78		P=0.05
February	1.04	0.88	0.92	0.95	0.19
April	0.21	0.26	0.23	0.23	0.04
June	0.41	0.39	0.31	0.37	0.05
August	0.96	0.87	0.80	0.88	0.39
October	1.16	0.93	1.18	1.09	0.12
December	0.97	0.89	0.86	0.98	0.12

There was no pronounced clonal variation in stomatal conductance. However, in water stress period, Bannockburn 157 showed lowest conductance which can be considered as a desirable character. In droughty condition, Phoobshering 312 showed highest rate of stomatal conductance compared to other genotypes. In case of mature plants, Bannockburn 157 showed highest conductance in February, June, August,

October and December while Tukdah 78 showed lowest conductance in June, August, October and December compared to other varieties. In case of young plants, Bannockburn 157 showed higher conductance in February, August, October and December while Tukdah 78 showed lowest rate in June, August and December. The annual range of stomatal conductance in case of Bannockburn 157, Phoobshering 312 and Tukdah 78 was 0.21–1.16, 0.26 – 0.93 and 0.23 – 1.18 cm s^{-1} respectively.

Transpiration (E)

High rate of transpiration was observed in October and December followed by August. Lowest rate was found in April (Table 4)

There was no definite trend ofclonal variation in transpiration. The annual range of transpiration in Bannockburn 157, Phoobshering 312 and Tukdah 78 was found to be 2.3 – 5.9, 2.7 – 5.5 and 2.6 – 5.8 m mol m^{-2} s^{-1} respectively.

Table 4:
Seasonal changes in transpiration rate (E) (m mol m^2 s^{-1}) of three genotypes of tea.

Month	Clones			Mean	LSD
	B157	P 312	T 78		P=0.05
February	3.4	3.0	3.4	3.3	0.70
April	2.3	2.7	2.6	2.5	0.49
June	3.1	3.8	3.2	3.4	0.62
August	4.1	4.4	3.7	4.1	0.72
October	5.9	5.6	5.8	5.7	0.88
December	5.4	5.0	4.4	5.1	0.37

Leaf Water Potential (Ψ)

Leaf water potential was lowest in April and high in June and August (Table 5). Moderate range of potential was found in October and December. February showed higher leaf water potential than April, but lower than all other months.

In all the cases, Bannockburn 157 showed highest leaf water potential, while Tukdah 78 showed lowest potential. The annual range of leaf water potential in Bannockburn 157, Phoobshering 312 and Tukdah78 was – 8.0 to – 13.9, -8.7 to – 15.7 and –9.3 to – 17.0 bar respectively.

Table 5 :
Status of leaf water potential (-bar) in experimental plants :

Month	Clones			Mean	LSD
	B157	P 312	T 78		P=0.05
February	13.6	14.8	16.5	15.0	1.92
April	13.9	15.7	17.0	15.5	2.70
June	8.5	8.7	9.9	9.0	2.17
August	8.0	8.9	9.3	8.7	0.92
October	12.2	13.0	14.2	13.1	2.64
December	11.5	12.3	14.3	12.7	2.23

Leaf Temperature (T L)

Leaf temperature was highest in April, closely followed by June and lowest in February (Table 6). During October and December, moderate range of leaf temperature was noticed.

Phoobshring 312 showed higher leaf temperature than other two genotypes. The annual range of leaf temperature of Bannockburn 157, Phoobshering 312 and Tukdah 78 was found to be 17.4 – 28.7°C, 16.8 – 29.0°C and 17.2 – 28.2°C respectively.

Table 6 :
Status of leaf temperature (°C) in experimental plants

Month	Clones			Mean	LSD
	B157	P 312	T 78		P=0.05
February	17.4	16.8	17.2	17.1	1.16
April	28.7	29.0	28.2	28.6	1.07
June	27.8	28.6	28.1	28.2	2.05
August	27.3	28.2	27.7	27.7	1.18
October	26.9	27.2	26.7	26.9	1.60
December	23.9	22.5	22.0	22.8	1.11

Net Photosynthesis And Individual Weather Parameters

(a) Air temperature and Net photosynthesis

Influence of ambient temperature in different months on the rate of net photosynthesis is depicted in Fig.1. Temperature was high during April, June and August but lowest rate of net photosynthesis was observed during April. This shows that suppression of net photosynthesis in April was due to some other factors. Comparatively low rate of net photosynthesis was observed during February when the ambient temperature was lowest. In the months of October and December when air temperature was moderate, highest rate of photosynthesis was observed.

(b) Photosynthetically active radiation and net photosynthesis.

Influence of PAR in different months on the rate of net photosynthesis is presented in Fig. 2 . PAR was very high in April and October but just contrasting picture emerged as far as the rate of net photosynthesis was concerned. While in October, photosynthesis rate was highest , it was lowest in April. It denotes that PAR was not a limiting factor, other factors were involved in affecting the rate of net photosynthesis in April adversely. The effect of PAR did not seem to be promising if the rate of net photosynthesis in June and August is compared. In August, photosynthetic photon flux density was lowest and in June and rate was quite high, but net photosynthesis was almost at par.

(c) Sunshine hour and net photosynthesis

Influence of sunshine hours (bright sunshine) in different months on the rate of net photosynthesis is presented in Fig. 3. Highest sunshine hour was observed in April, the month which saw lowest rate of net photosynthesis. Sunshine was moderate in October and December when the photosynthesis rates were very high. Low sunshine was observed in June and August when moderate rate of net photosynthesis was recorded.

(d) Relative humidity and net photosynthesis

Influence of relative humidity in different months on the rate of net photosynthesis is presented in Fig. 4. In April relative humidity was lowest and so was the rate of net photosynthesis. During February, when the relative humidity was a little higher than April but lower than all other months, the rate of net photosynthesis was low. During June and August , when very high humidity was observed, net photosynthesis was moderate. In October and December, when moderate relative humidity was moderate, very high rate of net photosynthesis was recorded.

(e) Wind velocity and net photosynthesis

Influence of wind velocity in different months on the rate of net photosynthesis is presented in Fig. 5. The effect of wind velocity on net photosynthesis was not consistent. During April and June, wind velocity was very high but in April, the rate of net photosynthesis was lowest while in June it was moderate. In the months of February, August, October and December- wind velocity was almost at par but net photosynthesis varied widely during these months.

Conclusions

1. During drought stress, most of the physiological parameters were influenced by moisture deficit. Net photosynthesis, stomatal conductance, transpiration and leaf water potential were lowest during water stress. Because during that period – temperature, sunshine hour and wind run were favourable. High light intensity might also have limited the physiological activities, to some extent, because there are reports that under moisture stress, high light intensity may retard the physiological processes.
2. Atmospheric moisture stress was found to play a more important role than soil moisture under droughty condition. Because in February (winter), soil moisture was found to be lowest but the physiological parameters viz. net photosynthesis, stomatal conductance, transpiration, leaf water potential showed higher values compared to April. The reason is that during February, relative humidity was higher than that of April, owing to foggy condition and dew fall. There are reports that fog and dew quenches the water requirement of plant to a considerable extent. In April, excessive evaporation from guard cells might have affected stomatal closure.
3. High percentage of moisture, heavy rainfall, low light intensity, low sunshine hour were found to limit physiological processes. During June and August, the rate of net photosynthesis was lower than that of October and December because of the aforestated factors. Although in June and August – the air and soil temperatures were high, it could not influence the rate of net photosynthesis inpositive direction.
4. Low temperature was another limiting factor for net photosynthesis. During winter, the rate of net photosynthesis was lower than monsoon and post – monsoon because of low temperature and of course, low moisture content.
5. The post – monsoon season was found to be most conducive for physiological activity. It showed high rate of net photosynthesis, transpiration, stomatal conductance etc. During post-monsoon, the light intensity was high, temperature was moderate, soil and atmospheric moisture were moderate, wind velocity was also moderate. This shows that neither too high nor too low range of temperature, moisture, wind, sunshine hour etc. is suitable for optimum growth.
6. High light intensity was not found to be a limiting factor as long as moisture content was adequate. During October, light intensity was highest, while the rate of net photosynthesis, stomatal conductance and transpiration was also highest.
7. In terms of net photosynthesis – stomatal conductance and transpiration showed strong positive correlation. While weak positive correlation was found, with leaf water potential. On the other hand, net photosynthesis showed weak correlation with leaf temperature.
8. Among the three clones, Bannockburn 157 was found to have higher rate of net photosynthesis in most part of the year, while Tukdah 78 had shown lower rate. Under moisture stress, Bannockburn 157 exhibited lowest rate of net photosynthesis.
9. Bannockburn 157 showed high rate of leaf water potential throughout the year while the leaf water potential of Tukdah 78 was the lowest.
10. Although stomatal conductance, transpiration and leaf temperature showed seasonal variations, there was no marked difference among the three clones in respect of those parameters.

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